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and the shadow is a black spot much larger than that of any other satellite, not excepting the third. This would seem to shew that the fourth is the largest satellite, though, when seen off the disc, it generally appears to be the smallest, and is always, I think, the least luminous."

"The variation of brightness seems to indicate a revolution on its axis. I have no doubt that in a less degree the third satellite is partially obscured by dark shades or spots; for when seen on the face of *Jupiter*, its form is an irregular oval, though the shadow is round."

Mr. Lassell proposes to re-examine these satellites with care when *Jupiter* is next in opposition.

*On an improved Compensation-Balance.** By Mr. Hartnup, Director of the Liverpool Observatory.

"The Liverpool Observatory was established chiefly for rating and testing the chronometers of vessels which sail from that port. In a large majority of cases the seaman relies solely on his timekeepers for the determination of longitude, and is frequently unable to employ any other means. Hence it became my especial duty, as director of this establishment, to devote my attention particularly to everything which could improve the going of marine chronometers. On my appointment I gladly availed myself of the permission of the Astronomer Royal to make myself fully acquainted with the process of rating chronometers at the Royal Observatory, and I have mainly adopted the plan followed there.

"The chronometrical department of the Liverpool Observatory was opened to the public in the summer of 1844, and several chronometers belonging to North American packet ships were sent to be rated. The same chronometers were returned to the observatory in the following winter, after having made the voyage to New York and back. On comparing the land-rates given in the summer with the sea-rates made during the voyage, these did not differ very sensibly in those chronometers which had gone steadily at the observatory in the summer; but on rating them again in the chronometer-room, they were found to be *losing more* by from one to four seconds a-day. The chronometer-room had no fire in it, and the temperature, which in the summer had been about 60°, was now only 40°. As I supposed the change of rate arose from change of temperature, I removed the chronometers to my sitting-room, in which the temperature was about 60°, when they immediately returned to their former rates. The chronometers were removed

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* The reader will bear in mind, that the fault of all watches furnished with the usual compensated balance is to *lose* in *extreme* temperatures when compensated for a *mean* temperature; or, what is the same thing, to *gain* in a *mean* temperature if going correctly in extreme temperatures.

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from one room to the other several times, and the rates were changed, in consequence, with very great regularity and consistency. I became satisfied, from a few more experiments, that the chronometers ordinarily employed in the merchant-service were imperfectly compensated. I applied to my committee, and obtained leave to have an apparatus made for testing chronometers in heat, which, when finished, was perfectly satisfactory.

"As the transit-instrument and clocks are of the highest class, I had now all the means for inquiry which could be desired. I had already compared daily all the chronometers entrusted to my care, and recorded the daily extremes of temperature to which they were exposed. I now commenced a record of the sea-rate, when it was attainable, of every chronometer which passed through the observatory.

"From an inspection of these records, it appears, 1st, That no sensible change of rate seems to be produced, in ordinary cases, either by the motion of the ship or by magnetic attraction. My experiments are to a certain extent defective, as I have no good authority for the rates at foreign sea-ports; but I feel convinced that the general effect produced on the rates of chronometers, from the above causes, is so small as to be of little practical importance.*

"2dly, That well-made chronometers, *when new*, gain on their rates, excessively for the first few months (in some cases this gaining on the rate continues for two or three years), and gradually arrive at their fixed rate. There appears to be no chance of lasting good performance unless the balance-spring is made hard, and the tendency of new chronometers to gain on their rates seems to depend on this, for when the spring is soft they are not so affected. The inconvenience of this gaining on the rate is often very great (in some cases of serious consequence to the ship-master), and the probability of its occurrence in new or re-sprung chronometers cannot be too strongly impressed on his mind. It is not uncommon for new chronometers, which have been sent to sea too soon, to return in three or four months with an increased gaining rate of 8 or 10 seconds a-day; and the ship-master, not knowing the cause, not unfrequently loses all confidence in an excellent chronometer, which has thus, as he conceives, deceived him.

"3dly, When the balance-spring has been in use for many years, the elasticity becomes so much deteriorated as to render the performance very uncertain. Chronometers which have been going for 20 or 30 years with the same balance-spring, scarcely ever keep

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* We shall probably soon have a most searching series of experiments on the going of chronometers at sea. Our Associate, Mr. Bond, is commissioned by the American Government to measure the arc of longitude between Boston and Liverpool *chronometrically*. Arrangements for the expedition are now in progress, and we look with great interest to the result, not merely as our astronomical link which connects Europe with America, but as likely to throw great light on more than one *vexata quæstio* in navigation.

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a steady rate, however good their performance may have formerly been. With proper means for testing, this fault cannot escape detection; the defect shewn in the performance is similar to that of a new chronometer with a soft balance-spring: the rate, in either case, may be steady while the chronometer is kept in a temperature nearly uniform, but in a fluctuating temperature the rate will change in the most capricious manner. This defect in the performance may be removed by the application of a new balance-spring; after which the chronometer goes through the process of gaining on its rate exactly the same as a new chronometer. The elasticity of the balance-spring may be so much deteriorated that no dependence can be placed on the performance, when to all external appearance the spring is quite free from rust or injury. There are many chronometers in the merchant-service which from this fault are worthless, and which are nevertheless carried to sea voyage after voyage, and from year to year, although in most cases an expense of a few pounds in respringing would render them as efficient as ever.

"4thly, Between the periods at which the chronometer ceases to gain on its rate and that at which the elasticity of the balance-spring becomes deteriorated, very great confidence may be placed in the rates of a large majority of the chronometers employed in the merchant-service; the imperfect manner in which the ordinary balance acts may be traced with ease, and tables of corrections may be formed, depending on the temperature, which may be applied successfully. There is nothing in the foregoing statement which is not perfectly well known, I believe, to all experienced makers.

"I have been in the habit of giving with chronometers which have been sent to the observatory the rate which corresponds with various degrees of the thermometer; and if the chronometers are kept in a place not liable to rapid changes of heat, and the time is brought up each day by the rate assigned to the temperature noted, I feel satisfied that a large number of the time-keepers now made would give very satisfactory longitudes. But this mode of carrying on the time requires a peculiar rating, which, so far as I know, is only practised at this observatory, and demands, besides, more attention from seamen than they are usually inclined to give. Many attempts have been made to produce a more perfect compensation, and it is acknowledged by all skilful makers that this is at present the great desideratum in the improvement of chronometers.

"I have always considered it a part of my duty to give every facility to makers in testing their chronometers. Several makers in Liverpool have availed themselves of the advantage thus afforded to them by the observatory, and amongst others Mr. William Shepherd, of 13 Bath Street, Liverpool, sent his new chronometers to the observatory to be tested previous to their being sold. I was in the habit at this time of pointing out to those makers who took

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an interest in the matter the defective state of the ordinary balance, as shewn by my experiments, and the ease with which the means at my disposal enabled me to detect any fault or improvement; and on doing this on one occasion to Mr. Shepherd, he remarked that he had tried many experiments on the balance, but had not been successful, and that if I could suggest any method which I conceived would remove the tendency to lose in extremes, he would make up the balances for me to try experiments with. I agreed to do so on condition that the results of our experiments, in the event of their being successful, should be made known for the benefit of the public, and to this Mr. Shepherd, without hesitation, consented. I had many discussions with Mr. Shepherd, and made several trials, from which I concluded,—

"1st. That the balance-rim must be of a circular form, so that the laminæ of brass and steel might be turned down to the requisite proportions with facility, and that the compensation and poising might be easily effected, as in the ordinary balance.

"2d. That the balance must be so contrived that the compensating rim and weights should move towards the centre with an accelerating velocity in an increasing temperature, while in a decreasing temperature they must recede from the centre with a gradually diminishing velocity.

"I need not mention those attempts which were either unsuccessful or which from difficulties of workmanship were not likely to be practically of use. I will describe that which is found to be easy of execution, and which is sensibly perfect in its operation.

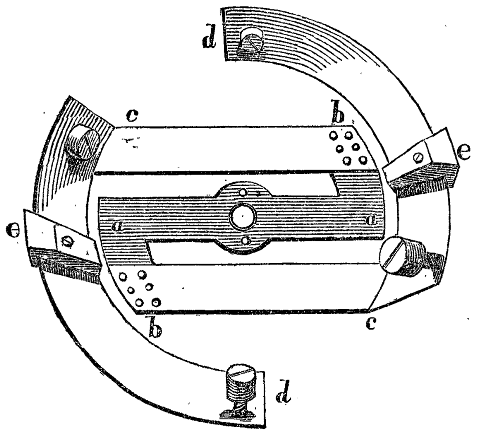

Fig. 1.

"In Fig. 1 the rim *c d*, *c d*, is composed of a strip of brass outside and a strip of steel inside, united as in the ordinary balance, and it differs from the rim of the ordinary balance only in its being *bevelled*, the angle being 45 degrees or thereabouts, as shewn in the elevation fig. 2. The bar *a a*, with the ears *a b*, *a b*, and also the bars *b c*, *b c*, are composed of brass and steel united,

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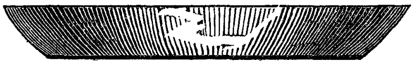

Fig. 2.

as in the rim; *a a* has the brass uppermost, and *b c*, *b c*, have the steel uppermost, and they are firmly joined at *b*, *b*: *e*, *e* are compensating weights, which slide on the rim as in the ordinary balance. The screws shewn near *c*, *c* and *d*, *d* are timing and poising screws.

"Now the effect of the inclined position of the rim is this: the different expansion of the two component strips carries the weights *e*, *e*, to and from the centre, and also up or down in a *slanting* direction, owing to the bevelled form of the rim. The *slant* takes off from the action of the rim, but this is increased to the proper amount, at mean temperatures, by setting the weight more forward on the rim, so that the balance is compensated for small changes. So far the new construction acts exactly as the ordinary compensated balance.

"To shew how the new balance acts in extreme temperatures, first take the case of extreme heat. The ends of the bar *a a*, bend downwards, and the ends of the bars *c b*, *c b* curve upwards, and the compound effect of these two curvatures is to set the bevilled rim more nearly perpendicular to the plane of the balance, whence the effect of the compound rim in bringing the weights *e*, *e* towards the centre is greater than it would have been in its more inclined position. Now this tends to shorten the time of vibration of the balance. In the ordinary construction, a chronometer *loses* in extreme heat; the new construction, therefore, tends to compensate the losing rate in extreme heat.

"Again, in extreme cold, the ends of *a a* bend upwards, and the ends of *b c*, *b c*, bend downwards, from the unequal contraction of the brass and steel strips which compose the bar. The effect of this compound action is to set the rim flatter, or more nearly parallel with the plane of the balance. Hence the effect of the compound rim will be less effective in removing the weights *e*, *e* from the centre than in the ordinary construction, and the balance will move more quickly. A balance of the ordinary construction *loses* in extreme cold, hence the new balance tends to compensate the error.

"I find by my experiments that a chronometer furnished with the new balance is sufficiently compensated in all degrees of heat and cold, for a proof of which I refer to Table I. This contains the daily rates of the first three chronometers to which the above description of balance was applied from Jan. 16, to March 2, 1848, with the daily range of temperature to which they were exposed. The brass boxes containing the chronometers were suspended in gimbals, in the same way as chronometers are kept when at sea, during the whole time, thereby insuring uniformity of position under all changes of temperature.

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“ TABLE I.

Name of Chronometer, William Shepherd.

Date 1848.		222 Daily Gain.	228 Daily Gain.	230 Daily Gain.	Temperature. Highest.	 Lowest.
		s	s	s	°	°
January	16	—1·0	—1·4	—2·4	85	70
	17	—0·5	—1·3	—1·9	87	85
	18	—0·7	0·1	—0·8	43	34
	19	—1·9	—0·2	—1·0	35	31
	20	—1·7	—0·6	—1·3	64	62
	21	—0·5	—0·2	—1·3	65	62
	22	—0·8	0·8	—1·2	36	33
	23	—0·9	0·8	—0·7	34	31
	24	—1·5	0·6	—1·1	37	31
	25	—1·5	0·2	—0·2	38	33
	26	—1·4	—1·2	—1·2	36	32
	27	—1·4	—0·9	—0·7	73	70
	28	—0·2	—0·9	—2·2	103	95
	29	—0·4	—0·7	—1·7	26	20
	30	—0·8	—1·1	—0·3	40	28
	31	—0·1	—0·8	—0·3	43	34
February	1	—0·9	—1·7	—1·4	75	68
	2	0·6	—0·8	—1·2	103	93
	3	1·0	—0·2	—2·4	105	93
	4	1·3	—0·1	—0·9	50	48
	5	0·8	—0·5	—1·6	53	49
	6	1·1	0·0	—1·5	60	53
	7	0·8	—0·2	—1·5	80	73
	8	0·8	—0·1	—1·6	103	93
	9	1·2	0·4	—1·7	93	85
	10	1·3	0·3	—0·8	70	65
	11	1·3	0·5	—1·0	100	91
	12	0·8	0·5	—2·1	95	87
	13	1·0	0·3	—1·1	62	56
	14	1·0	0·2	*	54	51
	15	0·6	—0·1	1·0	55	52
	16	0·4	—0·1	0·6	90	85
	17	0·8	0·2	0·0	98	90
	18	0·7	—0·1	0·2	38	31
	19	0·1	—0·2	0·2	45	39
	20	0·4	—0·4	1·2	55	50
	21	0·6	0·1	1·6	70	65
	22	0·8	0·6	1·2	98	91
	23	0·8	0·7	0·8	90	85
	24	1·0	0·8	0·8	90	88
	25	1·2	0·9	1·0	97	92
	26	1·6	0·3	1·7	58	54
	17	1·7	0·6	2·1	57	53
	28	1·9	0·8	2·3	57	53
	29	1·6	0·7	Rate closed.	59	53
March	1	1·4	0·4		55	51
	2	1·4	0·5	0·4	55	50

* “The weights were moved a little further from the arm, as the chronometer appeared to lose more in heat than in cold.”

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"For extreme cold the chronometers were exposed to the open air on the north side of the building; for all other temperatures they were either placed in the chronometer-room or in the heating apparatus. This apparatus is heated with hot air produced by the burning of gas, the pressure of which is regulated by a *governor*, and any definite temperature from that of the room to upwards of one hundred degrees may be kept for any required time, with a variation not exceeding two or three degrees in twenty-four hours. The artificial heat thus applied can do no more injury to chronometers than would heat arising from natural causes, and the removal of the wooden box in which the chronometer is suspended in its gimbals is rendered quite unnecessary, since heat applied in this way has little tendency to split or warp the wood.

I have given the daily rates in Table I. that they may be compared with the daily rates of chronometers with the ordinary balance, through the same range of temperature; but with the means possessed at the Liverpool Observatory, the power of the balance to compensate perfectly through a long range of temperature may be tested much more expeditiously, and the experiments repeated as often as desirable. I will give an example of the method of testing which I have practised, and which shewed, in a few hours' trial, the defect in all the constructions which were devised by me, and made by Mr. Shepherd, previous to that which I have described.*

"In my first experiments with the new balance I had ascertained what I had not been able to make out with the ordinary balance,—namely, that by a sudden change in the temperature of 20° or 30°, the balance-spring was affected sooner than the balance, and that a sudden immersion into a temperature higher by 20° or 30° caused the chronometer to lose, during the first hour, two or three tenths of a second more than it afterwards did by continued exposure to the same temperature. By sudden immersion into a lower temperature of 20° or 30° the same variation took place, but with a contrary sign, and the chronometer gained two or three tenths of a second more during the first hour than afterwards. But by changing the temperature *gradually*, and at the rate of not more than 8° or 10° an hour, the balance appears to be sensibly affected as soon as the spring.

"To shew the difference between the ordinary and the improved balance, I subjoin Table II., which contains the rate of the same chronometer with balances on the two constructions. Col. 1 is the interval in decimals of a day, at the beginning and end of which the chronometer was compared by coincident beats with a sidereal chronometer, and the highest and lowest temperatures noted.

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* "By a test similar to that in Table II. an improvement was shewn in the very first balance with the dished rim, and by the application of the compound centre bar it was rendered so perfect that I have not yet been able, notwithstanding the numerous experiments which I have since tried on twelve consecutive chronometers of this construction, to detect any sensible tendency either to lose or gain in extremes."

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Col. 2 is the deduced daily rate. Cols. 3 and 4, the temperatures. These are in the order of time. At the side are two other columns, in which the daily rates are arranged in order of temperature.

“ TABLE II.

William Shepherd, 222. *Ordinary* Balance.

	In order of Time.			In order of Temperature.	
	Daily	Temperature.		Daily	Mean
Days.	Gain.	Highest.	Lowest.	Gain.	Temperature.
	s	o	o	s	o
0·242	−5·8	47	37	−9·0	34·5
0·683	−0·7	82	65	−5·8	42·0
1·084	−2·4	102	82	−3·7	50·5
0·064	−4·1	108	102	−1·0	65·0
0·684	−5·8	113	108	−0·7	73·5
0·542	−5·6	113	102	−1·7	83·5
1·180	−1·7	102	65	−2·4	92·0
0·767	−1·0	65	65	−4·1	105·0
0·685	−3·7	65	36	−5·6	107·5
1·001	−9·0	36	33	−5·8	110·5

William Shepherd, 222. *Improved* Balance.

	In order of Time.			In order of Temperature.	
	Daily	Temperature.		Daily	Mean
Days.	Gain.	Highest.	Lowest.	Gain.	Temperature.
	s	o	o	s	o
0·375	−2·9	34	33	−2·5	28·5
0·500	−2·4	33	32	−2·4	32·5
0·127	−3·2	33	32	−3·2	32·5
0·980	−3·4	73	33	−2·9	33·5
0·249	−3·6	103	73	−2·9	37·0
0·753	−1·9	103	95	−3·2	51·5
1·000	−2·5	35	22	−3·4	53·0
1·002	−2·9	40	34	−2·4	71·5
0·125	−3·2	68	35	−3·6	88·0
0·875	−2·4	75	68	−2·0	88·5
0·250	−2·0	102	75	−1·9	99·0

“ Between the trials with the old and new balances, the chronometer was not cleaned. Nothing whatever was done to it, except the detaching of the old balance from the spring, securing the new one to it, and adjusting the weights of the new balance, so as to effect the compensation. The variation of rate due to extreme temperature in this chronometer *with the ordinary balance* is about the quantity which I have usually found in good chronometers from a similar change of temperature.*

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* “ Immediately subsequent to these experiments, I requested Mr. Shepherd to allow me to ask to have the same chronometers tested at the Royal Observatory. Not that I had the least doubt on my own mind as to the efficiency of the balance, but because I thought the principle would be sooner adopted by chronometer-makers, on a successful report appearing from Greenwich, than by any other means which I could adopt. The Astronomer Royal, on my application to him, very kindly obtained permission to have this done, and the rates of the three chronometers in Table I. are published in the list of trials for 1848.

“ Selecting from the Greenwich rates the two weeks of highest and lowest

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"The disadvantage of the new balance is, so far as I know, merely in the additional trouble of construction. Mr. Shepherd thinks that it requires at least twice the labour of the ordinary balance. The

temperature, and that which corresponds the nearest to the mean between them, we have the following rates:—

"*William Shepherd.*

	222 Daily Gain.	228 Daily Gain.	230 Daily Gain.	Temperature. Max.	 Min.
	s	s	s	°	°
March 11 to 18	−2·7	−1·1	−0·5	46	40
April 1 to 8	+1·0	+0·4	−1·2	71	63
May 6 to 13	+1·4	+0·5	−3·1	110	85

"Selecting again another set in a similar way, in which the temperatures are not very widely different, we have

	222 Daily Gain.	228 Daily Gain.	230 Daily Gain.	Temperature. Max.	 Min.
	s	s	s	°	°
April 22 to 29	+0·9	−0·3	−2·2	58	46
July 1 to 8	+0·2	+1·1	−0·5	77	57
June 17 to 24	+1·6	+2·0	−2·4	107	82

"Now, by comparing the two sets, it will be seen that the rates differ from each other in similar temperatures, nearly as much as they differ from each other, in each set, in different temperatures; and it appears to me that the law of variation between the balance and spring cannot be deduced from such discordant results.

"The trial does, however, shew that the chronometers did not go so steadily at Greenwich as at Liverpool; and I can account for this in no other way than by supposing that it arose from the chronometers being taken out of their gimbals, which I now understand was done at Greenwich.

"I understand from Mr. Shepherd, that No. 228 was purchased by the Government; Nos. 222 and 230 were again tested by me subsequent to the Greenwich trial. In the wooden boxes mounted in gimbals the rates were as steady as those given in Table I. When out of the gimbals, and standing on the table, a projecting pin at the bottom of the brass box inclined the face of each chronometer at an angle of about 4°, more or less, depending on which side of the face was elevated, the pin not being in the centre of the bottom of the box. In this state the rates were quite as discordant as the Greenwich rates, owing, as I at the time supposed, to the inclined position of the chronometer; but I now think that part of the irregularity arose from the unsteady way in which the box was supported: resting, as it did, on the end of the pin and the rounded part of the bottom of the brass box, the vibrations of the balance might cause the chronometer to attain an oscillatory motion. I understand from Mr. Shepherd, that the chronometers had only been poised in the callipers.

"There is no difficulty in making chronometers go at nearly the same rate with the 3, 6, 9, and 12 upwards; but when this is done, box chronometers generally gain several seconds a-day more with the face upwards than in any of the above-named positions. I am not aware of any method of getting rid of this fault, except that of making the chronometer fast in the short vibrations; but the remedy is certainly worse than the disease.

"So far as my experience goes, an error in positions of 10^s or 15^s is of little practical importance in chronometers employed for nautical purposes. I have tested a great many timekeepers of different makers, and have frequently found chronometers, which have been celebrated for their steady rates when free in their gimbals, upwards of half a minute a-day out in positions.

"This is, however, a question which has no bearing on the balance which I have described, since that may be poised in positions with as much facility as the ordinary balance."

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advantage is, that when made to compensate for any two distant temperatures, such, for instance, as 60° and 90°, or for 30° and 60°, I have found the compensation equally perfect in the lowest temperature which I have been able to obtain, or in the highest that I could risk the chronometer in, and sensibly the same in all intermediate temperatures. I have subjected chronometers with this description of balance to temperatures as high as 124° and as low as 20°, and whenever a loss has been found at one extreme, a tendency to gain at the other extreme has invariably presented itself. Under these circumstances, and as I understand from Mr. Shepherd that he applies this description of balance to all the chronometers which he now makes, pocket as well as box, I am anxious to make it known that chronometer-makers and the public may avail themselves of it if they think fit."*

Description of a small Transit-room, with Section and Plan.

By Mr. Dell.

The dimensions of this room are 7½ feet in the meridian, 5½ feet wide, and 6½ feet high. By placing the pier and window-slits a good deal on one side, Mr. Dell finds he has room enough for the clock and a desk.

The instrument,—a 30-inch transit by Jones,—stands on a stout stone, resting on a brick pier, which descends 2½ feet below the ground. The building itself is of wood, which, being screwed together, can be taken apart and set up again in a very short time, if necessary. The cost, including labour and materials, did not exceed 6*l.*

Mr. Dell is well satisfied with the steadiness of the instrument.

Before placing the transit in the meridian, Mr. Dell observed η *Ursæ Majoris* and γ *Draconis* on the prime vertical, and deduced, as a mean result, Lat. 51° 48′ 54″·7 N.

The observatory was found, by measurement, to be 522 feet south and 295·5 feet east of Aylesbury spire, or 5″·1 and 0$^{\text{s}}$·31 respectively. Adopting the data of the survey, viz.—

N. Lat. = 51° 49′ 1″·0 and 3$^{\text{m}}$ 17$^{\text{s}}$·07 W.,†

Mr. Dell's observatory is in

Lat. 51° 48′ 55″·9 N. and Long. 3$^{\text{m}}$ 16·76 W.

Mr. Dell also finds,—

Hartwell Observatory	4679 feet South,	6842·8 North of Aylesbury Spire
Stone Observatory	6577 ——	11330·0 ——

The Rev. J. B. Reade recommends that the eyehole of the ordinary negative, or Huyghenian, eyepiece should be much reduced

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* "I hope shortly to have an opportunity of testing this balance in the extreme temperatures of Cambridge, U.S."

† Is this the longitude of the published survey, in which an erroneous figure of the earth was used, or a corrected longitude? The difference is about 0$^{\text{s}}$·8.